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ABSTRACT

Arguing that understanding what lies behind the apparent usability of direct manipulation style interfaces might not only help in building better interfaces, but can also draw attention to possible side effects, this paper uses examples from a prototype data manipulation system to pursue a characterization of direct manipulation interfaces as forestalling the need for procedural reasoning, a class of skills that people appear to have difficulty mastering. Two issues are raised: (1) whether direct manipulation is a design philosophy that will inhibit the development of procedural reasoning skills, and (2) the significance of procedural reasoning proficiency for users in the future. The design philosophy is then examined in terms of the reasoning skill and the reasoning skill in terms of the design philosophy, with the intent of shedding some light on both. It is concluded that direct manipulation techniques could be useful in explicitly teaching procedural reasoning skills; that procedural reasoning is just one alternative perspective; and that some of the issues raised here might look different as more complex direct manipulation systems are developed, and their resolution will have to be based on empirical work. Thirteen references and 60 technical reports by members of the Institute for Cognitive Science are listed. (Author/MES)

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David Owen

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Understanding what lies behind the apparent usability of direct manipulation style interfaces might not only help in building better interfaces but can also draw attention to possible side effects. With the help of examples from a prototype data manipulation system, this paper pursues a characterization of direct manipulation interfaces as forestalling the need for procedural reasoning, a class of skills that people appear to have difficulty mastering.

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Direct Manipulation and Procedural Reasoning

DAVID OWEN

The concept of direct manipulation (DM) in human-computer interaction can refer to anything from the feeling the user gets while interacting with a system to the apparent concreteness of the way objects are visibly represented and influenced Hutchins, 1986; Hutchins, Hollan, & Norman, 1986; Schneiderman, 1983). Although the latter is probably more appropriate here, a precise definition is not crucial; in fact, useful distinctions will only become clear as our understanding the properties of such systems develops.

The term *procedural reasoning* has a more precies definition. Sheil states "procedural reasoning is the process by which one determines the effect of a set of instructions or, alternatively, the set of instructions that will achieve a particular effect" (1981). With such a definition, procedural reasoning is clearly a skill that has much to do with programming but that also has its place in design and analysis in many other domains. In fact, Sheil argues that it is a basic skill that will be required more and more frequently by nonprogrammers to fully exploit programmed devices. Procedural reasoning is also a skill that people appear to have difficulty mastering (Ferguson & Henderson, 1986; Pea, 1986).

This paper pursues a characterization of DM-style interfaces as forestalling the need to be skilled at procedural reasoning. This characterization can explain why people (at least initially) find such interfaces attractive: they become empowered in spite of their lack of procedural reasoning skills. However, we must ask whether DM is a design philosophy that inhibit the development of procedural reasoning skills. There is no a priori answer to this question or to how significant procedural reasoning proficiency will be for users in the future. In this paper, I examine the design philosophy in terms of the skill and vice versa with the intent of shedding some light on both. If the characterization is convincing then it might contribute to the continuing debate about the future educational role of computers.

PROCEDURAL REASONING

The definition of procedural reasoning indicates when this skill is required, but it says nothing about what the skill entails, why it is difficult to learn, or how the skill may be developed. One fundamental characteristic of procedural reasoning is that instructions for action must be understood or created in the absence of the action itself. People find this difficult: 70% of the students in a college-level introductory computer course were unable to develop an algorithm for making a local telephone call (Ferguson & Henderson, 1986). This finding could be misleading since no details of the experimental context are given, but presumably all the students could make a local telephone call. It is not hard to find other situations where generating instructions is troublesome. Interactions with attorneys, hairdressers, travel agents, and so on can all involve giving instructions intended to achieve a particular effect.

Separating intent from action, as Sheil puts it, implies a language—some way in which to refer to the world and express an intent to some interpreter or agent. The success of the interaction depends on the overlap between language/world mappings of the two participants. This can be a fairly severe

constraint, but in most common communications between people a number of mechanisms enhance the apparent overlap, taking up slack in the literal expression. For example, people share generally similar backgrounds, physiological constraints, and experience, and therefore they share many goals, expectations, and conceptualizations of the world. This sharing supports people's capacity to make sensible inferences in the face of many ambiguities in an expression. If ambiguities remain, the fact that people share a language acquired through a similar training process affords a meta-language with which to probe for clarification and perhaps debug the reasoning of the generator. Failing that, it is often possible to refer to the physical world by pointing or demonstration. These mechanisms are in general so successful that the plasticity in the notion of "meaning," that an expression is open to an infinity of interpretations, is hardly noticed. We are thereby insulated from an awareness of some of the most rigorous demands of procedural reasoning.

So two key factors serve to greatly minimize the extent to which our everyday communication makes demands on procedural reasoning skills: an approximately common conception of the world and a common language. Although these two factors are not truly independent, it is interesting to make that simplifying assumption and to look at their separate contributions. Removal of the language commonality not only means that some kind of translation of the expression must be undertaken by the generator, but it also means the loss of the meta-language for probing and repair. This is to some extent a serious loss since it limits the capacity for developing the necessary overlap in the language/world mapping of the generator and the interpreter. The loss of a common conceptualization of the world involves a translation of a different kind. For the expression of intent to have any meaning to the interpreter, the informational microstructure inherent in the generator's conceptualization of the world must be unpacked to a level that allows a match to that of the interpreter. At the very least this will also impact the vocabulary of the common language. In the physical world, action partitions statements about state changes, such as moving from the car to the telephone booth, for example, and governs information flow, such as punching in a telephone number in a particular way. The informational microstructure of each of those acts is normally of no interest, and although the physical constraints may allow several options for action, many of the logically possible operations are implicitly precluded by the physical constraint of the domain (see Norman, 1987, for example). For successful communication however, the microstructure must be abstracted from the surface form of the action and translated into different groupings of information flow and state change that correspond to the predilections of the new interpreting device. This in turn can only be done on the basis of an understanding of the new interpreter's conceptualization of the world. The mere appreciation of the possibility and consequences of this degree of plasticity of perception is a major step, over and above the skills required to actually do it.

In some sense, the limiting extreme of withdrawal from expressing intention is just to perform the action directly. This relegates a listener to the role of observer, making it harder to infer intent and thereby contribute to accomplishing the task. But it has what might be considered positive consequences for how the task can be encoded by the actor. For example, if the ramifications of each step in an action sequence are reflected in the new state of affairs, they need only be recognized rather than remembered. At each execution step the task can be reassessed in light of what the last step accomplished. In contrast, generating instructions for performing even a familar task requires planning. Sequences of steps must be developed by reconstructing, in the absence of context, the consequences of each step that are relevant to the next step or indeed any subsequent steps.

THE DIRECT MANIPULATION PARADIGM

The computer, with its unique representational world, removes the heretofore transparent safety net from beneath users, exposing them to the unforgiving reality of what procedural reasoning can involve. It is a medium in which infinitely many languages and world conceptualizations are realizable, unfettered by the more commonly occurring practical and time constraints (Owen, 1986). The response embodied in the basic DM paradigm approximates the worldly strategy of maximum retreat from the

need for procedural reasoning. It promotes the illusion that users are carrying out actions themselves in a visible world populated by more or less recognizable domain objects and tools. With continual representation of state, the possibility of a step-by-step approach returns and "physical" constraints on what is possible can be mimicked. The world is reconstructed symbolically to empower users with the most basic and familiar means of expressing intent—namely, pointing, which is the fall-back position in the world when language fails.

SOME EXAMPLES

Figure 1 is taken from a piece of code written to construct a subset of some experimental data and hand it to an analysis of variance (anova) program. It uses an excellent and successful data-analysis package developed by Perlman [Perlman 1986]. The first line calls the data massager **dm**, which is told to read in file *DataFile*, perform an operation on it based on the first four arguments, and output the results into the new file *Out.1*. The data file must consist of one record per line, each with the same number of fields. From each input record, **dm** extracts four fields (second (*s2*), third (*x3*), etc.; *s* and *x* indicate data type) to create a new output record. An additional constraint is that only records coded *T* are used. (In the data the first field codes trials as (P)ractice, (V)oid or (T)rial.) The second line of code calls the **anova** program, which outputs an analysis of variance of the data in *Out.1* to file *Anova.1*. The four arguments supply meaningful names for use in the output.

In this example, users confront the more severe demands of procedural reasoning. In general, it is necessary to understand and maintain lengthy reasoning chains about the form of *DataFile*, the relationship between it and *s2*, *s1*, *x4*, and so on, the consequences those relationships may have for the order in *Out.1* and eventually for the way the program **anova** is called. In particular, the formulation and expression of criteria for excluding records is made algorithmically.

Figure 2 shows the first part of the same task executed in a prototype data manipulation system, a redivision of the task means subparts do not exactly correspond. The x-axis of the graph is connected to a particular field of the data set using mouse clicks on appropriate tags. The "DO-IT" button is "pushed" and in the absence of a y-axis input, a histogram is generated. Columns representing allowed records can be singled out by selecting them with the mouse (column *T*). Pushing the "SUBGRAPH" button then results in a new data set, containing just the selected records; it appears in the graphed menu of data sets in the top left pane.[1] Compared to the similar portion of the task in Figure 1, the prototype system supports a representation by the user, of both situation and task, not based on abstraction and description, fundamental components of procedural reasoning, but based on what Suchman calls "situated action" (Suchman, 1985).

```
dm "if s1 = 'T' then s2 else KILL" x3 x4 x5 < DataFile > Out.1

anova Subj Block Cond Data < Out.1 > Anova.1
```

FIGURE 1.

[1] It is also possible to select points on a graph and select fields by interaction with the data set image. These kinds of facilities can be invaluable in allowing selections that are essentially inaccessible to descriptive techniques. The reverse is also true, but this trade-off is not the central issue here.

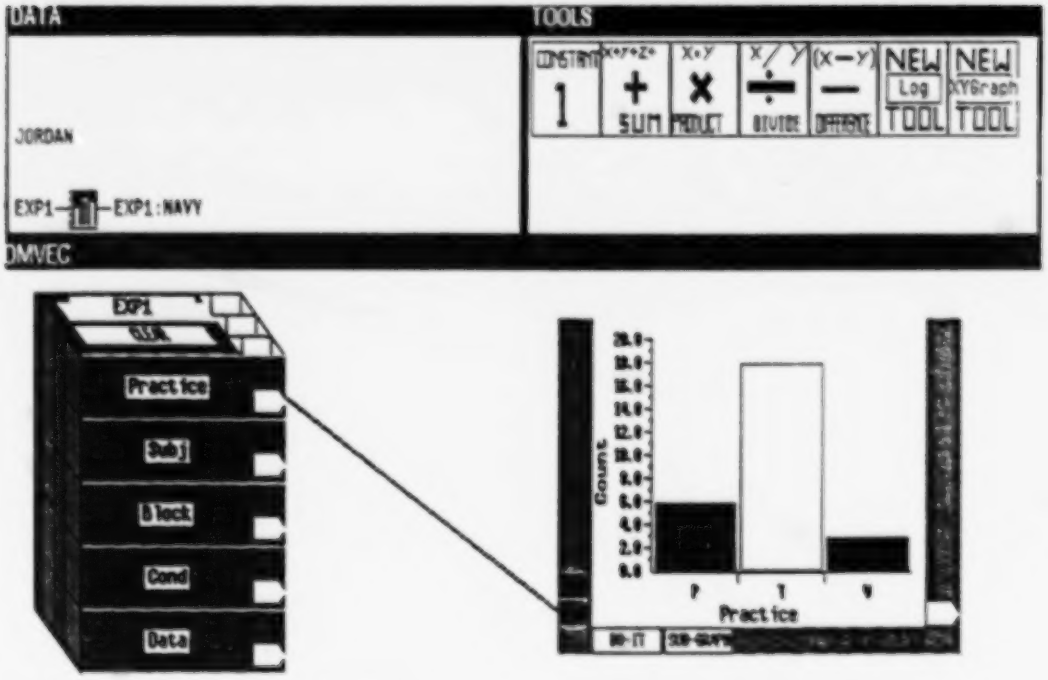

FIGURE 2. **Selecting data subsets via a histogram.**

In Figure 3, an operator that computes the mean interstroke interval from key-stroke data has been constructed by linking together the appropriate tools. The new operator can be encapsulated, concealing its structure and added to the menu of available tools. Compensating for the lack of an informed cooperative interpreter, the form and context in which expressions are made greatly limit the possibility of syntax errors, and by bearing an obvious analogical relationship to what is expressed, the form assists users in recalling what they have done. There is a price paid for this support, however, and that is the pedestrian feel of the approach. For example, notice that in both Figures 2 and 3 the labels for the axes of the graphs are automatically inferred from what the user has constructed. This presents the attractive possibility of allowing users to create a graph by typing an expression for each axis label onto a blank graph using the appropriate data set as argument. The appropriate operator could then be constructed by the system instead of the user and could be displayed for editing as required. But contrary to the spirit of DM, this introduces a command language and dramatically increases the possibility of both syntactic and semantic errors, increasing the need for more substantial procedural reasoning skills. This example also points to the importance of separating out the use of clear representations of domain objects and world state, one major component of DM, from any implications concerning how the user goes about affecting the world.

IS THERE A PROBLEM?

The most positive analyses of the DM philosophy examine the relationship between how a system represents a domain, the typical user goals in that domain, and what the user must do to achieve those goals. One can argue that DM encourages users to be occupied mainly with objects in the domain of interest, investing minimum effort in the vagaries of the medium. Assessing the validity of this

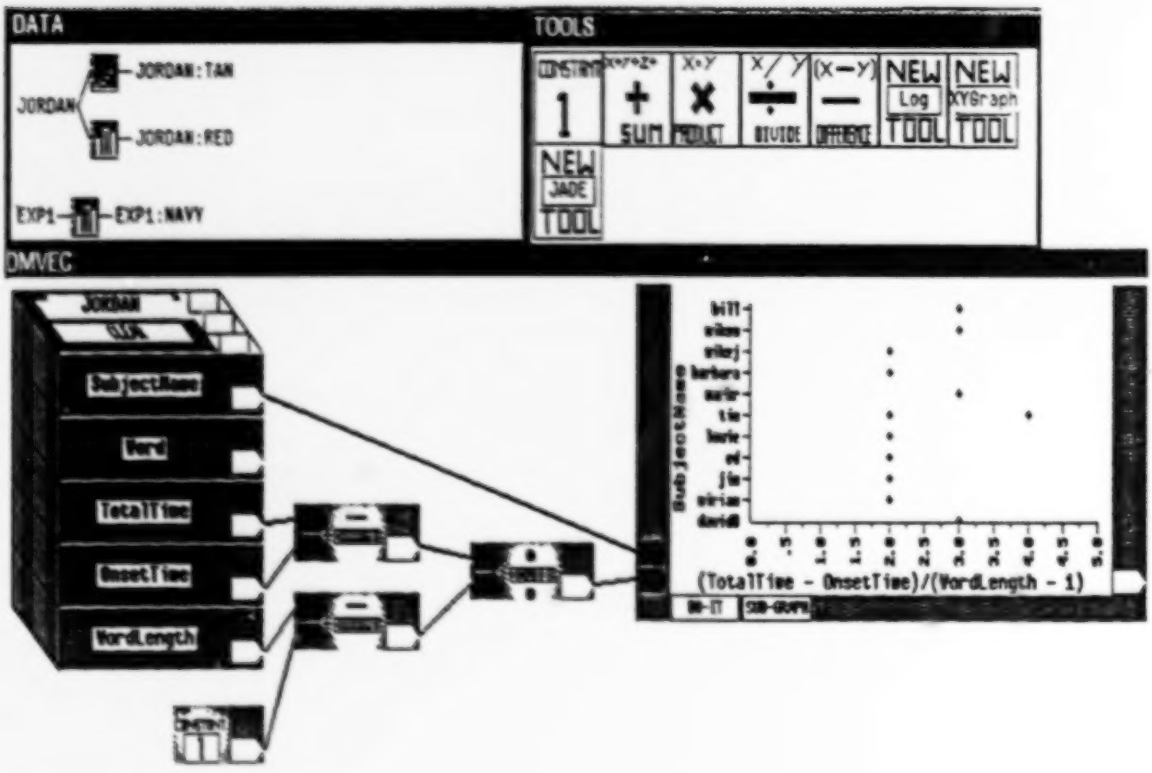

FIGURE 3. Building of a new operator.

argument is not the objective here. The emphasis is not so much on the nature of the relationship per se as with how it is achieved, and accommodating people's unfamiliarity and inability to cope with the rigors of procedural reasoning is seen as a major factor. The significance of this hinges on a number of issues that can be raised here but not resolved.

First is the question of whether people will need more sophisticated procedural reasoning skills, as Sheil argues, to take advantage of the technology that finds its way into everyday life. There is no short discussion of this question but techniques that make some degree of functionality available with minimum overhead to users with differing agendas and experience will probably always have a place.

Second, if the development of procedural reasoning skills is important, then will the availability of systems that tend to circumvent the need for those skills, however clumsily, inhibit that process? Will the temptation to cling to inefficient ease inhibit the development of a more elegant form of expression? The factors influencing skill transfer between domains are, in fact, not clear in general (Papert, 1985; Pea, Kurland, & Hawkins, 1985). Nevertheless these questions can be unpacked a little further by reconsidering some of the components of procedural reasoning and techniques for circumvention and support that have been identified.

Providing a world in which a detailed representation of the current state is coupled with the availability of step-by-step progression towards a goal approximates "situated action" (Suchman, 1985). While this may be a good environment for exploring a domain, as Suchman points out, it does little to encourage the development of detailed coherent plans based on the precise projection and representation of future states. It might match well with how people naturally operate, but successful procedural reasoning requires the fomulation of plans that are considerably less vague.

The irritation of unfamiliar syntactic rules has been minimized by encouraging action but so too has the need for abstraction and the formulation of unambiguous referents been minimized. There is some evidence that this need for abstraction in turn reduces the likelihood of forming a representation of a successful action sequence that can be of use in other domains or that can be accessed by any means other than re-enactment (Levin et al., 1986).

The tendency of DM systems to represent basic logical and informational constraints as interactional constraints often relieves the user of the need to be aware of them. However part of being skilled at procedural reasoning, as opposed to being skilled at using a particular system, is just such an awareness; a familiarity and ease with recognizing and accommodating different classes of such constraints.

SUMMARY

To characterize DM as a philosophy that minimizes the need for procedural reasoning skills is not to attack it in its primary role, but to examine it from a perspective other than that of the relationship between a user's goals and a system's representation of a domain. If incidental contact with the need for procedural reasoning skills is significant to their development, then it is important to recognize when that contact is being reduced. In fact DM techniques could be useful in explicitly teaching procedural reasoning skills. Procedural reasoning is just one alternative perspective: some of the issues raised here might look different as more complex DM systems are developed, and their resolution will have to be based on empirical work.

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